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WIND TUNNEL TESTS ON THE TRIMMING OF AIRCRAFT SKIS

REPORT NO. PAA-13

BY

J. J. GREEN

DIVISION OF MECHANICAL ENGINEERING

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DIVISION OF Physics & Engineering (Aeronautics)

FOR REFERENCE Dept. of National Defence - Aeronautical Engineering Division
Letter from S/L A. Ferrier to J.H.Parkin, Jan. 28, 1933

SUBJECT Wind Tunnel Tests on the Trimming of Aircraft Skis

AUTHOR J. J. Green

APPROVED ..... DIRECTOR

Summary

Introduction - Reasons for Investigation

In a previous report (No. PAA-6) information is given concerning the aerodynamic pitching moments on full sized aircraft skis. These moments give rise to considerable forces in the trimming cables at the front and rear of the skis. The Air Ministry is sending a Hawker "Audax" to Canada for winter trials and in view of its high performance and maneuverability some method of aerodynamically reducing the magnitude of the pitching moments on the skis is desirable when they are fitted to this aircraft.

Range of Investigation

The R.C.A.F. ski size "E" was chosen by the Department of National Defence as being suitable for the Hawker "Audax" and was therefore used in the tests described in this report.

The possibility of stabilising the ski by means of an aerofoil, suitably attached at the rear of the ski in a position well aft' of the ski axle, was examined theoretically and the requisite area of the aerofoil was determined.

Before examining the effect of this aerofoil experimentally, tests were carried out on the ski with various "turn-ups" at the keel to determine their effectiveness in modifying the pitching moment curve, so that it would be safe to operate the aircraft equipped with this type of ski. Three areas of turn-up were tested, the span being the same as the width of the ski (2 ft.) and the chords being 9 in., 12 in. and 15 in. respectively. Pitching moments on the modified ski were measured over a speed range of 70 to 100 m.p.h. and at incidences from -20 to +20°. In all three cases the turn-up was set at an angle of 135° to the upper surface of the ski.

The pitching moment due to the weight of the ski was also measured over the same range of incidences, in order that inertia pitching moments could be deduced for aerobatics in which high accelerations occur.

A symmetrical aerofoil was attached to the rear of the ski as far aft' as possible, in an attempt to stabilise it. Pitching moments on the ski for two different angular settings of the aerofoil with respect to it were measured over the same range of speed and incidences as used in the tests on turn-ups.

Conclusions

To balance completely the pitching moment on each ski, an aerofoil of approximately 2½ sq. ft. would be required.

The effect of turn-up at the heel of a ski is to increase the positive pitching moments. Negative pitching moments do not appear until incidences of the order of -15° are attained. This is very desirable since it is the negative moment which is considered to be dangerous in view of the possibility that the toe of the ski might drop sufficiently to cause the ski to turn right round.

Owing to the interference of the ski on the stabilising aerofoil, the resultant pitching moment curve still exhibits slight instability over the normal working range of incidence, which grows worse at the extreme angles. The effect of the aerofoil is to reduce considerably the forces existing in the trimming cables.

Introduction

The work described in this report is a continuation of the investigations commenced in a previous report (No. PAA-6) which outlines the wind tunnel measurements of the aerodynamic pitching moments on three full sized aircraft skis of modern design. These tests revealed the existence of pitching moments of considerable magnitude when the attitude of the ski departs appreciably from a slight negative incidence and since the ski exhibits an unstable pitching moment curve, the displacement of the ski itself tends to increase. These moments, which are proportional to the square of the flight speed, have to be counteracted by an elastic member such as trimming cables or a trimming leg and for this to be done successfully the member has to be so stiff that its utility is lost when the aircraft is taxying on the ground.

A Hawker "Audax" army co-operation aircraft is being sent to Canada by the Air Ministry for winter trials and in equipping this machine with winter landing gear, it is obvious that its high performance is such as to give rise to very large aerodynamic pitching moments on the skis. In view of the fact

that the centre of gravity of the skis is ahead of the axle, a negative inertia pitching moment exists which in rapid manoeuvers is liable to grow to large dimensions. With the present conventional method of trimming the skis, it is felt that a grave danger exists that, in the performance of rapid manoeuvers, the toes of the skis may be pulled down under the combined effect of inertia and aerodynamic loads and that the skis might be turned right around through 180°, with serious consequences. The question of adequate trimming gear therefore becomes important.

The Department of National Defence suggested that the simplest and most logical way to trim the skis is by attaching a horizontal aerodynamic stabilising surface on an outrigger at the rear end of the ski and disposed slightly above the axle so that the drag of the stabiliser will assist the lift forces in producing a stabilising moment. This, in conjunction with an elastic trimming gear, suitable for the function of taxying, ought to safeguard the ski under all conditions, by providing a stable pitching moment curve.

In addition, another suggestion was made, that, in place of the aerodynamic stabiliser, the effect of turning up the heels of the skis (as is done in Sweden) might be examined for beneficial effects on pitching moment.

For the investigation of these problems in the wind tunnel, an R.C.A.F. size "E" ski was forwarded to the Research Council. The size "E" ski, as fitted to the Bellanca "Pacemaker" was selected as suitable for the "Audax" from a knowledge of the all-up weight of this aircraft.

Aerofoil Stabiliser - Theoretical Work

For taxying over the snow, the size "E" ski is required to have 15° positive angular movement and 32° negative angular movement. From a knowledge of these figures, the rearmost location for aerofoil stabiliser on the ski was chosen, so that the stabiliser would not foul the lower main plane. A drawing is included showing the size "E" skis on the Hawker "Audax". The symmetrical R.A.F. 30 aerofoil was assumed and from a knowledge of its characteristics and location, its area was deduced, so that the aerodynamic pitching moment on the ski would be reduced approximately to zero at all reasonable incidences. It was found that for each ski an aerofoil of about 2½ sq. ft. (aspect ratio 6) would be necessary, located some 51" behind the ski axle and 2½" above it. This figure was liable to considerable error owing to the serious interference the stabiliser would be subjected to from the ski itself, especially at positive ski angles, which could not be allowed for in the calculations.

Before testing this device, which is sure to add considerably to the structure and air drag of the ski, it was decided to examine the effect of turning up the heel of the ski. It was thought that this might probably add a positive pitching moment

to the ski which would render it very unlikely that a resultant negative moment would ever occur in flight. It was felt that positive moments could be accommodated by a trimming leg whereas large negative moments could not be tolerated on account of the likelihood that the nose of the ski might drop and cause it to swing through 180°, in which case safe landing would be impossible.

Tests on Ski with a Turned-Up Heel

Experimental Procedure

Three areas of turn-up were employed with the hope of deducing an approximate relationship between area of turn-up and change in pitching moment.

The dimensions of the turn-up were as follows:

No. 1 ---------- span 2 ft. ----------chord 9 inches
No. 2 ---------- span 2 ft. ----------chord 12 inches
No. 3 ---------- span 2 ft. ----------chord 15 inches

The span in each case is the same as the width of the ski. Photographs (Fig. 1 and 2) are included which show the ski with turn-up. In each case the flat turn-up was attached to the ski by two steel brackets (see Fig. 2) so as to make an angle of 135° with the flat upper surface of the ski.

The experimental procedure in measuring pitching moments about the ski axle was identical with that used on previous occasions and fully described in Report No. PAA-6. The ski was supported in the wind tunnel jet on a horizontal shaft and a vertical wire from the front of the ski was attached to the balance above the jet. The incidence of the ski was varied in 5° steps from -20° to +20° and the wind speeds used in the tests ranged from 70 to 100 m.p.h.

At each incidence, the pitching moment due to the weight of the ski alone was measured, in order that the inertia pitching moment due to rapid accelerations on the aircraft might be evaluated and combined with the aerodynamic moment to give the resultant pitching moment on the ski.

Results

The results of these tests are given in Tables I, II, III and IV. On curve sheet No. 1 the pitching moments on the ski equipped with the different turn-ups at the heel are plotted, together with the pitching moment curve for the unmodified ski. Although not a non-dimensional coefficient, a quantity which is constant for each angle of incidence is obtained by dividing the measured pitching moment by the square of the wind speed. This has been called the pitching moment coefficient and has been plotted on curve sheet No. 1 for the various set-ups. In order, that the results might be applied readily to practical problems, the moment is in ft. lb. units and the wind speed in m.p.h.

The inertia pitching moment curve has been plotted on the same sheet in ft. lb. against incidence.

From the plotted curves it is seen that the effect of turn-up at the heel of the ski is to superimpose a positive pitching moment on that of the ski alone which is greatest at an incidence of about -5°. This renders the appearance of a negative moment impossible until an incidence of -13° is reached in the case of No. 1 turn-up and -17° for the No. 2 turn-up. It is not likely that in operation such incidences would be obtained, in view of the positive moment present at all other incidences and the relatively smaller inertia pitching moment arising in maneuvers.

If the positive moment can be tolerated, turning up the heel of the ski, in conjunction with suitable elastic trimming gear, appears to be a satisfactory way of taking care of the aerodynamic forces on the ski without impairing ground operation.

In using the inertia pitching moment curve to calculate the forces in trimming gear during maneuvers, some care must be exercised. For level flight and other steady conditions of flight in which the path is rectilinear, the curve gives the moment about the ski axle due to the weight of the ski, providing that the co-ordinate marked "angle of incidence of ski" is understood to mean the angle of the ski to the horizontal. In other conditions of flight in which accelerations are present and it is desired to estimate the moments arising due to these accelerations, the angle co-ordinate on Curve 1 must be taken as the angle by which the normal to the surface of the ski is in advance of the line of action of the resultant acceleration on the aircraft. The values of the moments given on the curve must then be multiplied by the value of the resultant acceleration in gravity units to give the moment about the ski axle.

A rough proportionality was found to exist between area of turn-up and the change in pitching moment produced by it, despite the different aspect ratios of the three turn-ups. On curve sheet No. 2, the mean value for the three turn-ups of the change in pitching moment coefficient per unit area of turn-up has been plotted against incidence. It shows that the maximum effectiveness of turn-ups occurs at -5° incidence and that they are considerably more effective at negative than at positive incidences, due to shielding by the rest of the ski in the latter case. Curve No. 2 can be used to determine what area of turn-up would produce a desired change in pitching moment.

Tests with a Faired Turn-up

From the results of the tests, it appears that the smallest turn-up (No. 1) would be quite satisfactory on the size "B" ski and it was suggested that the effect of fairing this turn-up into the rear of the ski by means of smooth curves should be examined. Accordingly, the rear of the ski was modified as

shown in the photographs (Fig. 3 and 4) and the drawing Fig. 5. Sheet metal plates were added to the top and bottom of the turn-up which faired it smoothly into the surfaces of the ski. The wooden formers used for the under surface are shown in Fig. 1 and 2 attached to turn-up No. 1. In this way a style of ski heel was produced which more closely resembles the type of heel which would be incorporated in the construction of new skis designed with turned-up heels.

The results obtained with the faired turn-up are given in Table V, and plotted on curve sheet No. 3. Very little effect is produced as a result of adding the sheet metal fairing; the pitching moments are all slightly increased in the positive sense.

Tests on Ski with Stabilising Aerofoil

Although the turn-up removes the danger of large negative moments, it still leaves a moderately large positive moment to be taken care of and the pitching moment curve still exhibits instability. It was decided to examine the utility of an aerofoil stabiliser based on the theoretical calculations made previously. In the absence of serious interference from the ski, this aerofoil should produce a neutral stability curve for the ski over a moderate range of angles ($\pm 20^{\circ}$).

The symmetrical RAF 30 section was used of chord 9 in. and span 43⅔ in., giving an area just less than 2⅔ sq. ft. This is slightly in excess of that required on theoretical grounds, but in view of the expected interference from the ski and the use of an aspect ratio less than 6 (the figure used in the calculations) this area was not considered excessive from the point of view of counteracting the moment due to the ski itself, but represented approximately the limiting size of stabiliser that might be practicable from other considerations.

The stabiliser was attached to the ski by means of two brackets, as shown in Fig. 6. The point on the chord at which the maximum thickness occurs was located 5¼" behind the ski axle and 2½" above it (ski horizontal) which gives the requisite clearance under the fuselage of the "Audax". Since the moment curve for the ski alone crosses the zero moment line at an incidence of $-4\frac{1}{2}^{\circ}$, the stabiliser was set at $+4\frac{1}{2}^{\circ}$ to the ski in the hope that it would give no moment at the same angle that the ski does.

Results

The results are given in Table VI and plotted on curve sheet No. 4. By deducting the moments due to the ski alone, the moment due to the aerofoil alone (including interference effects) is obtained and has been plotted on the same sheet.

It is obvious from the curves that the interference from the ski is so large that the moment curve still indicates instability. Over a range of some 15° in the middle, the aerofoil has substantially reduced the instability and even at

the extremes of the angle range, reduction in the magnitude of the moments has taken place. As was expected, at positive angles the aerofoil is least efficient, due to the powerful interference from the ski itself.

The moment due to aerofoil alone does not pass through zero at the anticipated ski incidence of $-4\frac{1}{2}^{\circ}$, due, presumably, to a downwash from the ski which delays the negative angle at which the stabiliser reaches zero incidence to the relative air stream.

Change of Stabiliser Angle

From an inspection of the moment curve, due to the combination, it was decided to try a second angle setting of the stabiliser, in order to produce a moment curve lying more on the positive side of the zero moment line. The stabiliser was therefore set at -3° to the ski and it was expected that this would shift its moment curve $7\frac{1}{2}^{\circ}$ along the angle axis, making it pass through the origin.

Results

The results are given in Table VII and plotted on curve sheet No. 4. The moment curve due to the combination now appears more satisfactory. Negative moments cannot appear until a ski incidence of -15° and only moderate positive moments exist between -15° and 0°. At -5° the slope of the moment curve tends to become very flat. Trimming the ski at this angle with trimming cables would be very simple and reliable.

From the moment curve due to the aerofoil alone, it appears that changing its angle does not merely shift its moment curve along the angle axis. Decreasing the angle of the stabiliser with respect to the ski has caused the addition of positive moments at all angles. The moment curves due to stabiliser alone show the stalling of the stabiliser at the extreme angles, except when the ski is at negative angles, in which case the effect of the ski is such that the stalling of the aerofoil is materially delayed, behaving as a slotted aerofoil, the ski acting as a crude auxiliary.

Effect of Off-setting Stabiliser Laterally

From an inspection of the drawing of the "Audax" fitted with the size "E" skis, it is obvious that the bombs on the lower main plane are vertically above the outer edges of the skis and that the addition of the stabilisers would render the present bomb location more than ever unsatisfactory unless the stabilisers were moved inboard until their outer tips were plumb with the edges of the skis. This, with the addition of a slight shift of the bomb racks out towards the wing tips would make the combination satisfactory. Further advantages would be obtained as a result of off-setting the stabiliser, since it would be partially removed from the influence of the ski itself

and secondly, it would be immersed in the higher velocity slip stream and would therefore be more effective.

Retaining the same angle and location for the stabiliser, it was moved laterally until one tip was plumb with the ski edge. Pitching moments on the combination were again measured.

Results

These are given in Table VIII and plotted on curve sheet No. 5. A slight improvement is noted over the central location for the stabiliser due to a reduction in the interference experienced by the aerofoil in the offset position.

It is felt that the effect of the slip-stream would be very important with this arrangement.

Conclusion

On curve sheet No. 5, a number of other curves have also been plotted for comparison, the most important one being the moment curve for the ski with faired turn-up. The superiority of the moment curve with aerofoil stabiliser is quite apparent, whereas, if the positive moment can be tolerated, the faired turn-up is obviously the simplest and cleanest modification and far less clumsy than the addition of a stabiliser.

Further Developments

Lift and drag on the skis with and without these modifications will be made when the wind tunnel balances are available. The effect on lift drag and pitching moment of simple stream lining will be examined.

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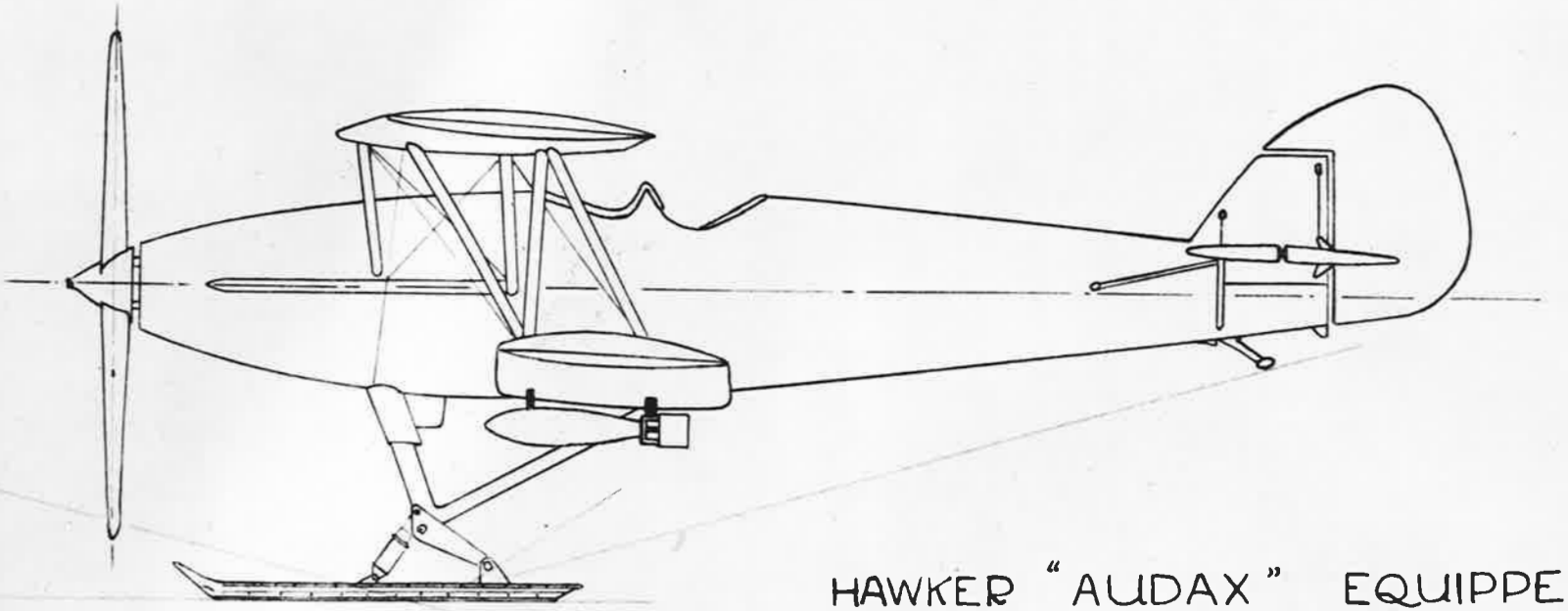
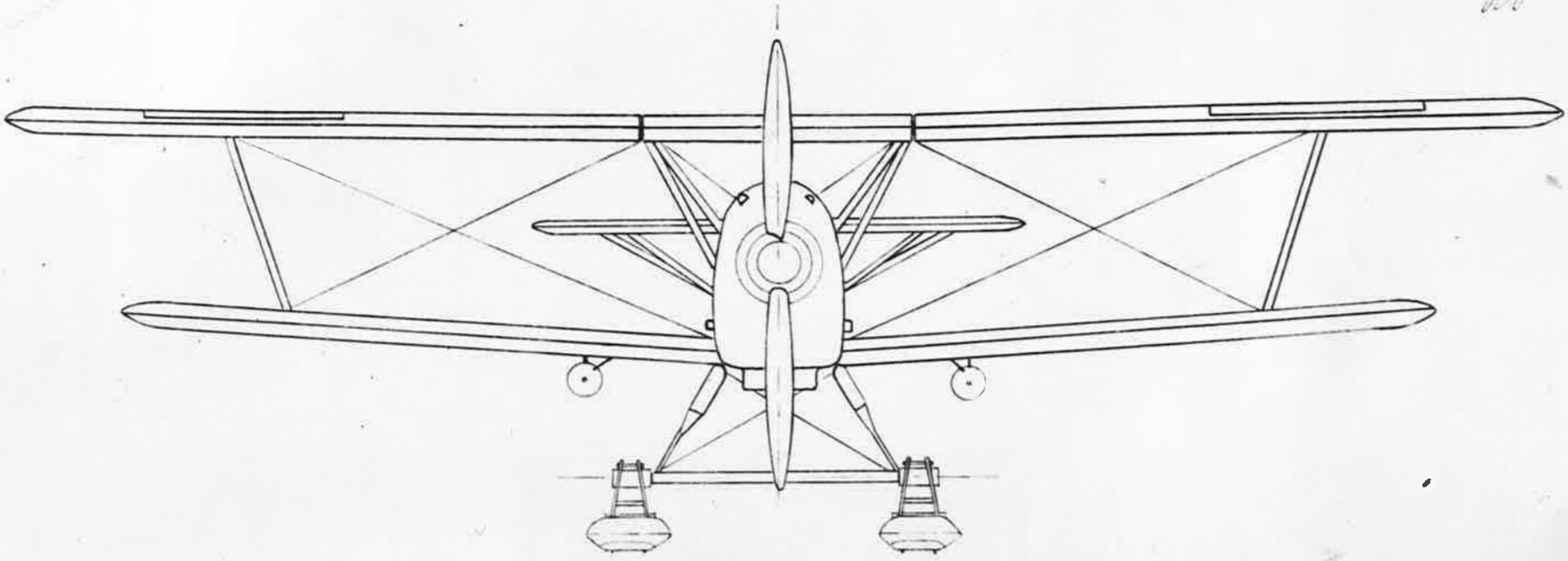


HAWKER "AUDAX" EQUIPPED WITH R.C.A.F SKIS SIZE 'E'

SCALE 1" = 4'. 13/2/33



INCIDENCE	MOMENT ARM. INS.	WIND SPEED V. M.P.H.	SCALE READINGS LBS. TARE	GROSS	NETT	$100\ M/V^2$ M. FT. LBS.	MEAN $100\ M/V^2$
−20°	45·10	70	77·25	52·80	− 24·45	−1·88	
		80	"	46·20	− 31·05	−1·82	
		90	"	39·10	−38·15	−1·77	−1·82
−15°	47·90	70	54·07	53·10	− 0·97	~~−0·079~~	
		80	"	48·20	− 5·87	−0·366	
		90	"	45·80	−8·27	−0·407	−0·390
−10°	50·34	80	21·80	30·80	9·00	0·590	
		90	"	34·10	12·30	0·637	
		100	"	36·80	15·00	0·629	0·619
−5°	52·55	80	34·20	55·10	20·90	1·430	
		90	"	60·30	26·10	1·412	
		100	"	66·70	32·50	1·425	1·422
0°	54·38	80	36·90	66·50	29·60	2·095	
		90	"	74·50	37·60	2·100	
		100	"	83·50	46·60	2·110	2·102
+ 5°	55·38	80	30·13	68·10	37·97	2·740	
		90	"	78·50	48·37	2·760	
		100	"	89·80	59·67	2·755	2·752
+ 10°	56·03	80	28·10	81·50	53·40	3·900	
		90	"	96·30	68·20	3·930	
		100	"	112·00	83·90	3·920	3·920
+ 15°	56·68	70	30·80	86·40	55·60	5·360	
		80	"	102·70	71·90	5·310	5·330
+ 20°	56·91	70	33·20	102·30	69·10	6·690	6·690

TABLE I.

PITCHING MOMENTS ON SKI WITH No. 1. TURN-UP (9 IN. CHORD) AT HEEL

INCIDENCE	MOMENT ARM. INS.	WIND SPEED V. M.P.H.	SCALE READINGS LBS. TARE	GROSS	NETT	$100\ M/V^2$ M. FT. LBS.	MEAN $100\ M/V^2$
-20°	45·10	70	75·95	57·10	-18·85	-1·45	
		80	"	52·80	-23·15	-1·36	
		90	"	47·80	-28·15	-1·31	-1·37
-15°	47·90	70	45·45	45·30	-0·15	~~-0·012~~	
		80	"	44·70	-0·75	-0·047	
		90	"	45·60	-0·85	-0·042	-0·044
-10°	50·34	80	20·70	36·20	15·50	1·017	
		90	"	41·70	21·00	1·088	
		100	"	47·20	26·50	1·112	1·072
-5°	52·55	80	33·00	61·70	28·70	1·965	
		90	"	69·60	36·60	1·980	
		100	"	78·10	45·10	1·975	1·973
0°	54·38	80	26·60	61·80	35·20	2·490	
		90	"	72·00	45·40	2·540	
		100	"	82·80	56·20	2·540	2·523
+5°	55·38	80	29·10	72·60	43·50	3·140	
		90	"	84·20	55·10	3·140	
		100	"	97·40	68·30	3·150	3·140
+10°	56·03	80	27·10	71·00	43·90	4·190	
		90	"	85·20	58·10	4·240	
		100	"	100·50	73·40	4·230	4·220
+15°	56·68	70	29·80	87·50	57·70	5·560	
		80	"	103·50	73·70	5·440	5·50
+20°	56·91	70	32·70	104·30	71·60	6·940	6·94

TABLE II

PITCHING MOMENTS ON SKI WITH No. 2. TURN-UP (12 IN. CHORD) AT HEEL

Incidence	Moment Arm. Ins.	Wind Speed V. M.P.H.	Scale Readings Lbs.			$100\ M/V^2$ M. Ft. Lbs.	Mean $100\ M/V^2$
			Tare	Gross	Nett		
−20°	45·10	70	40·30	26·70	− 13·60	−1·045	
		80	"	24·35	− 15·95	−0·938	
		90	"	21·65	−18·65	−0·866	−0·950
−15°	47·90	70	34·75	38·80	4·05	0·330	
		80	"	41·30	6·55	0·410	
		90	"	44·20	9·45	0·466	+0·402
−10°	50·34	80	19·30	46·80	27·50	1·803	
		90	"	54·40	35·10	1·818	
		100	"	64·80	45·50	1·910	1·844
−5°	52·55	80	17·75	54·30	36·55	2·50	
		90	"	63·10	45·35	2·45	
		100	"	73·60	55·85	2·45	2·47
0°	54·38	80	25·35	67·90	42·55	3·10	
		90	"	79·30	53·95	3·02	
		100	"	92·00	66·65	3·02	3·02
+5°	55·38	80	27·94	77·00	49·06	3·54	
		90	"	90·50	62·56	3·57	
		100	"	105·10	77·16	3·56	3·56
+10°	56·03	80	26·00	74·80	48·80	4·66	
		90	"	90·00	64·00	4·67	
		100	"	107·50	81·50	4·70	4·68
+15°	56·68	70	28·70	88·30	59·60	5·75	
		80	"	107·00	78·30	5·78	5·76
+20°	56·91	70	31·26	106·40	75·10	7·27	7·27

TABLE III

PITCHING MOMENTS ON SKI WITH No. 3 TURN-UP (15 IN. CHORD) AT HEEL.

INCIDENCE	MOMENT ARM. INS.	FORCE LBS.	MOMENT ABOUT AXLE. FT. LBS.
-20°	45·10	-10·1	-38·0
-15°	47·90	-13·6	-54·3
-10°	50·34	-16·6	-69·7
-5°	52·55	-19·3	-84·5
0°	54·38	-21·8	-98·8
+5°	55·38	-24·3	-112·2
+10°	56·03	-26·6	-124·3
+15°	56·68	-28·9	-136·5
+20°	56·91	-31·3	-147·5

TABLE IV.

PITCHING MOMENTS DUE TO WEIGHT OF SKI.

Incidence	Moment Arm. Ins.	Wind Speed V. M.P.H.	Scale Readings Lbs.			$100 \frac{M}{V^2}$ M. Ft. Lbs.	Mean $100 \frac{M}{V^2}$
			Tare	Gross	Nett		
-20°	45·28	70	75·31	52·8	-22·51	-1·73	
		80	"	47·5	-27·81	-1·64	
		90	"	40·7	-34·61	-1·61	-1·66
-15°	48·20	80	31·98	25·3	-6·68	-0·42	
		90	41·35	33·5	-7·85	-0·39	
		100	"	32·5	-8·85	-0·36	-0·39
-10°	50·48	80	25·10	36·0	10·90	0·72	
		90	"	39·5	14·40	0·75	
		100	"	42·4	17·30	0·73	+0·73
-5°	52·37	80	15·27	36·5	21·23	1·45	
		90	"	42·6	27·33	1·47	
		100	"	48·9	33·63	1·47	1·46
0°	54·38	80	18·55	48·7	30·15	2·14	
		90	"	56·6	38·05	2·13	
		100	"	65·4	46·85	2·13	2·13
+5°	55·34	80	21·36	61·3	39·94	2·88	
		90	"	72·3	50·94	2·90	
		100	"	84·3	62·94	2·91	2·90
+10°	56·47	80	24·22	80·2	55·98	4·12	
		90	"	95·3	71·08	4·13	
		100	"	112·8	88·58	4·17	4·14
+15°	56·70	70	26·95	83·0	56·05	5·41	
		80	"	100·7	73·75	5·45	5·43
+20°	56·70	70	29·63	99·3	69·67	6·72	6·72

TABLE V.

PITCHING MOMENTS ON SKI WITH No. 1. TURN-UP (9 IN. CHORD) FAIRED

INCIDENCE	MOMENT ARM. INS.	WIND SPEED V. M.P.H.	SCALE READINGS LBS. TARE	GROSS	NETT	100 M/V² M. FT. LBS	MEAN 100 M/V²	100 M/V² FOR AEROFOIL ALONE
−20°	44·89	70	71·12	43·3	−27·82	−2·125		
		80	"	35·5	−35·62	−2·083	−2·104	1·121
−15°	47·70	80	51·34	32·8	−18·54	−1·150		
		90	"	27·8	−23·54	−1·115		
		100	55·97	27·5	−28·47	−1·130	−1·145	0·797
−10°	50·25	80	50·06	40·8	−9·26	−0·606		
		90	"	38·2	−11·86	−0·614		
		100	"	35·3	−14·76	−0·618	−0·616	0·262
−5°	52·29	80	39·24	33·0	−6·24	−0·425		
		90	"	31·7	−7·54	−0·406		
		100	"	29·9	−9·34	−0·407	−0·413	−0·316
0°	54·42	80	41·98	41·3	−0·68	−0·048		
		90	"	41·2	−0·78	−0·044		
		100	"	41·1	−0·88	−0·040	−0·044	−0·814
+5°	55·57	80	31·16	40·5	9·34	0·676		
		90	"	42·4	11·24	0·644		
		100	"	45·0	13·84	0·641	0·654	−1·046
+10°	56·92	80	33·66	58·7	25·04	1·857		
		90	"	65·9	32·24	1·888		
		100	"	73·0	39·34	1·865	1·870	−1·030
+15°	57·64	80	22·71	75·2	52·49	3·94		
		90	"	89·9	67·19	3·98		
		100	"	105·3	82·59	3·97	3·960	−0·38
+20°	57·41	70	25·18	79·7	54·52	5·32		
		80	"	97·0	71·82	5·36	5·340	−0·32

TABLE VI.

PITCHING MOMENTS ON SKI WITH STABILISING AEROFOIL AT + 4½° TO SKI

INCIDENCE	MOMENT ARM. INS.	WIND SPEED V: M.P.H.	SCALE READINGS LBS. TARE	GROSS	NETT	$100 \frac{M}{V^2}$ M. FT. LBS.	MEAN $100 \frac{M}{V^2}$	$100 \frac{M}{V^2}$ FOR AEROFOIL ALONE
-20°	45·17	70	61·64	46·60	-15·04	-1·155		
		80	"	43·00	-18·64	-1·097		
		90	"	39·90	-21·74	-1·012	-1·088	2·137
-15°	47·83	80	56·10	56·20	0·10	0·006		
		90	"	56·90	0·80	0·040		
		100	"	57·50	1·40	0·060	0·035	1·976
-10°	50·25	80	50·12	60·50	10·38	0·680		
		90	"	62·90	12·78	0·661		
		100	"	66·30	16·18	0·678	0·673	1·551
-5°	53·25	80	34·37	47·20	12·83	0·890		
		90	"	50·40	16·03	0·879		
		100	"	54·10	19·73	0·876	0·882	0·979
0°	54·04	80	28·12	43·30	15·18	1·068		
		90	"	47·70	19·58	1·089		
		100	"	51·80	23·68	1·066	1·074	0·304
+5°	55·99	80	35·43	59·60	24·17	1·763		
		90	"	65·70	30·27	1·745		
		100	"	72·80	37·37	1·745	1·751	0·051
+10°	57·05	80	19·91	58·20	38·29	2·845		
		90	"	68·90	48·99	2·876		
		100	"	80·00	60·09	2·860	2·860	-0·040
+15°	57·47	70	22·59	68·90	46·31	4·525		
		80	"	83·00	60·41	4·520		
		90	"	99·50	76·91	4·546	4·530	+0·190
+20°	58·23	70	25·08	84·40	59·32	5·875		
		80	"	103·20	78·12	5·925	5·900	+0·240

TABLE VII

PITCHING MOMENTS ON SKI WITH STABILISING AEROFOIL AT -3° TO SKI

INCIDENCE	MOMENT ARM. INS.	WIND SPEED V. M.P.H.	SCALE READINGS LBS.			$100\ M/V^2$ M. FT. LBS	MEAN $100\ M/V^2$
			TARE	GROSS	NETT		
-20°	44·78	70	56·88	41·3	-15·58	-1·189	
		80	"	37·9	-18·98	-1·109	
		90	"	33·3	-23·58	-1·089	-1·129
-15°	48·35	80	42·02	43·1	1·08	0·068	
		90	"	44·2	2·18	0·108	
		100	"	45·3	3·28	0·132	0·103
-10°	50·85	80	45·48	57·5	12·02	0·798	
		90	"	61·1	15·62	0·818	
		100	"	65·1	19·62	0·832	0·816
-5°	52·41	80	25·05	39·6	14·55	0·989	
		90	"	43·9	18·85	1·013	
		100	"	48·4	23·35	1·016	1·006
0°	54·01	80	28·07	44·7	16·63	1·170	
		90	"	49·4	21·38	1·185	
		100	"	54·0	25·93	1·167	1·174
+5°	55·86	80	30·74	54·2	23·46	1·706	
		90	"	60·5	29·76	1·710	
		100	"	67·8	37·06	1·725	1·714
+10°	56·78	80	19·86	56·3	36·44	2·700	
		90	"	66·4	46·54	2·720	
		100	"	77·1	57·24	2·710	2·710
+15°	57·39	80	22·43	80·9	58·47	4·376	
		90	"	95·3	72·87	4·310	
		100	"	113·5	91·07	4·360	4·349
+20°	57·52	70	25·09	82·5	57·41	5·620	
		80	"	100·1	75·01	5·620	5·620

TABLE VIII.

PITCHING MOMENTS ON SKI WITH AEROFOIL AT -3° AND OFF-SET LATERALLY.

TRIMMING OF SKIS ON HAWKER "AUDAX"

PITCHING MOMENTS ON SINGLE SKI. COEFFICIENT M/V^2

M IN FT. LBS.

V IN M.P.H.

BELLANCA SKI SIZE "E"

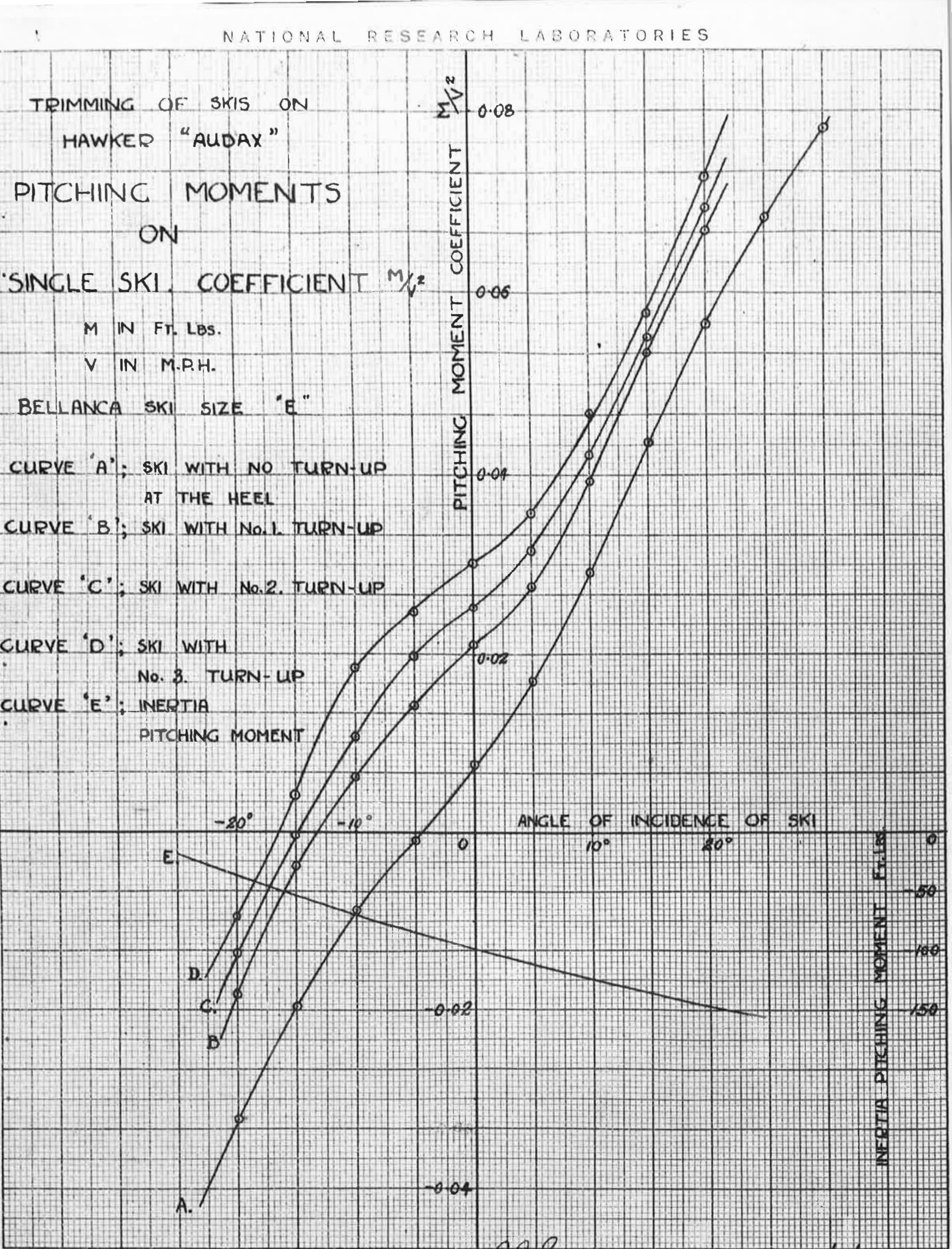
CURVE 'A'; SKI WITH NO TURN-UP AT THE HEEL

CURVE 'B'; SKI WITH No. 1. TURN-UP

CURVE 'C'; SKI WITH No. 2. TURN-UP

CURVE 'D'; SKI WITH No. 3. TURN-UP

CURVE 'E'; INERTIA PITCHING MOMENT



CURVE No. 1. SIGNATURE J.J. Green. DATE 4/7/33.

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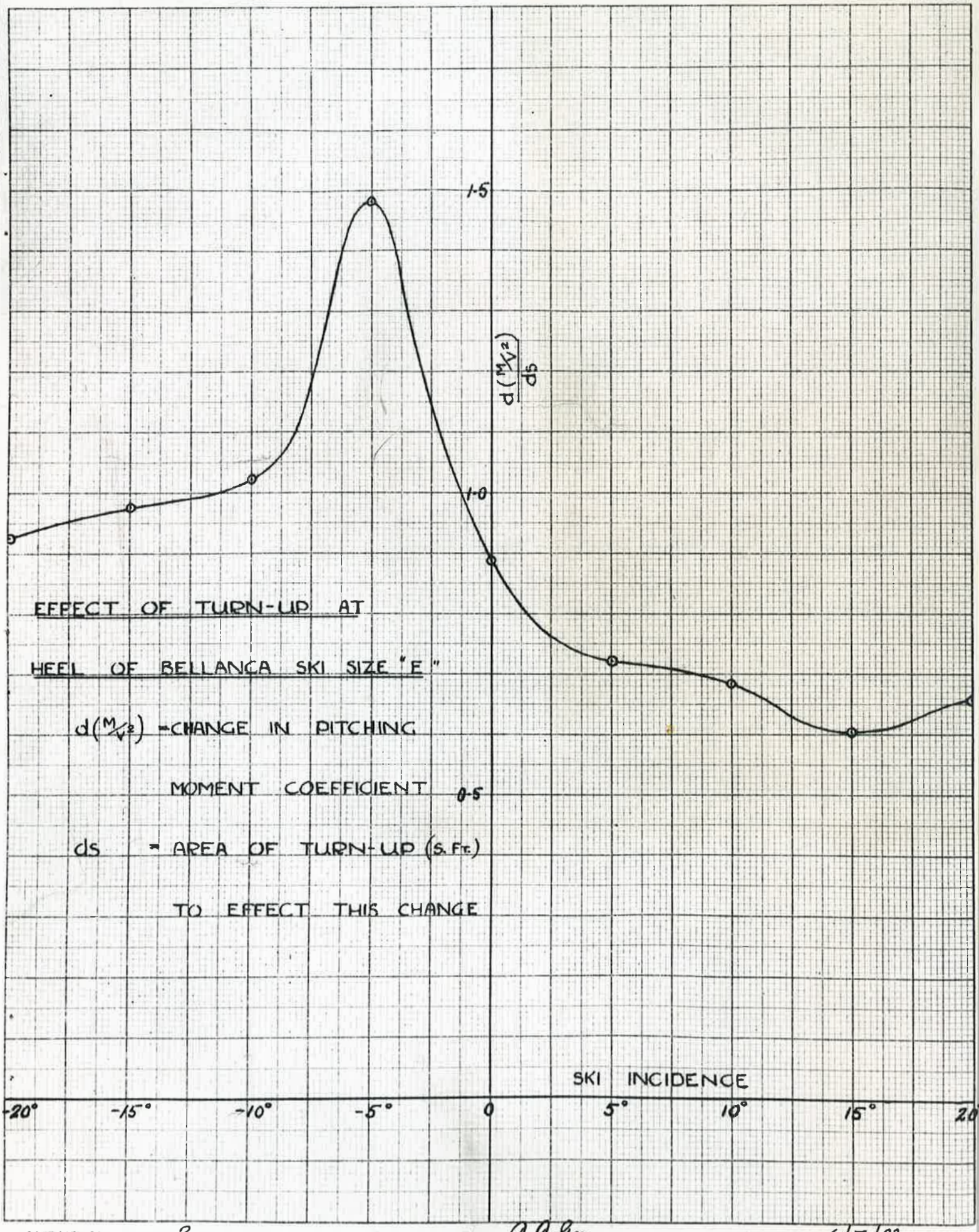

EFFECT OF TURN-UP AT HEEL OF BELLANCA SKI SIZE "E"

$d(M/V^2)$ = CHANGE IN PITCHING MOMENT COEFFICIENT

dS = AREA OF TURN-UP (S. FT.) TO EFFECT THIS CHANGE

CURVE No. 2. SIGNATURE J. J. Green. DATE 6/7/33

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PITCHING MOMENT CURVES

BELLANCA SKI SIZE "E"

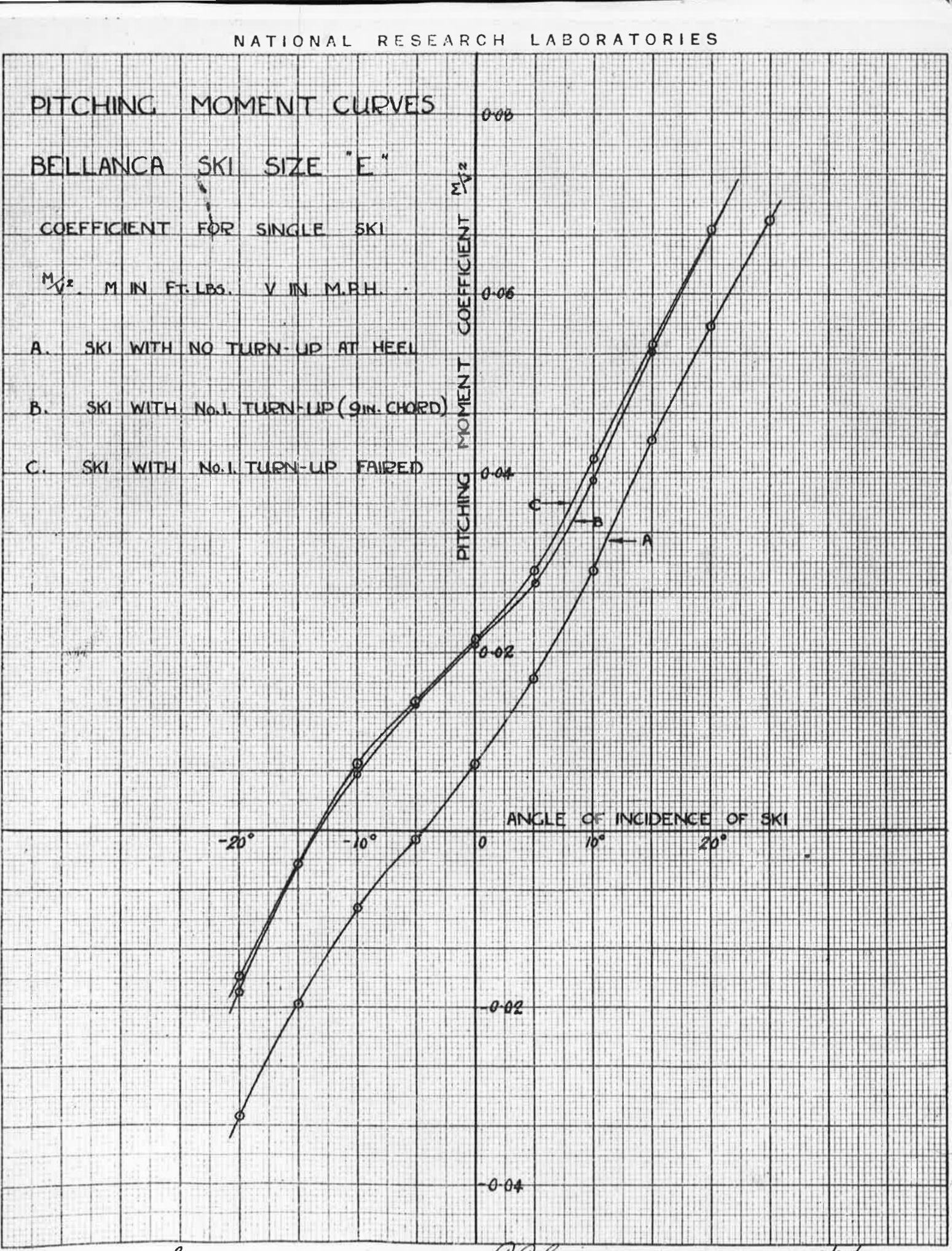
COEFFICIENT FOR SINGLE SKI

M/V^2. M IN FT. LBS. V IN M.P.H.

A. SKI WITH NO TURN-UP AT HEEL

B. SKI WITH No.1. TURN-UP (9 IN. CHORD)

C. SKI WITH No.1. TURN-UP FAIRED



CURVE No. 3. SIGNATURE G.J. Green. DATE 13/7/33.

R.C.A.F. SIZE "E" SKI.

PITCHING MOMENT ON SINGLE SKI.
(M IN FT. LBS. V IN M.P.H.)

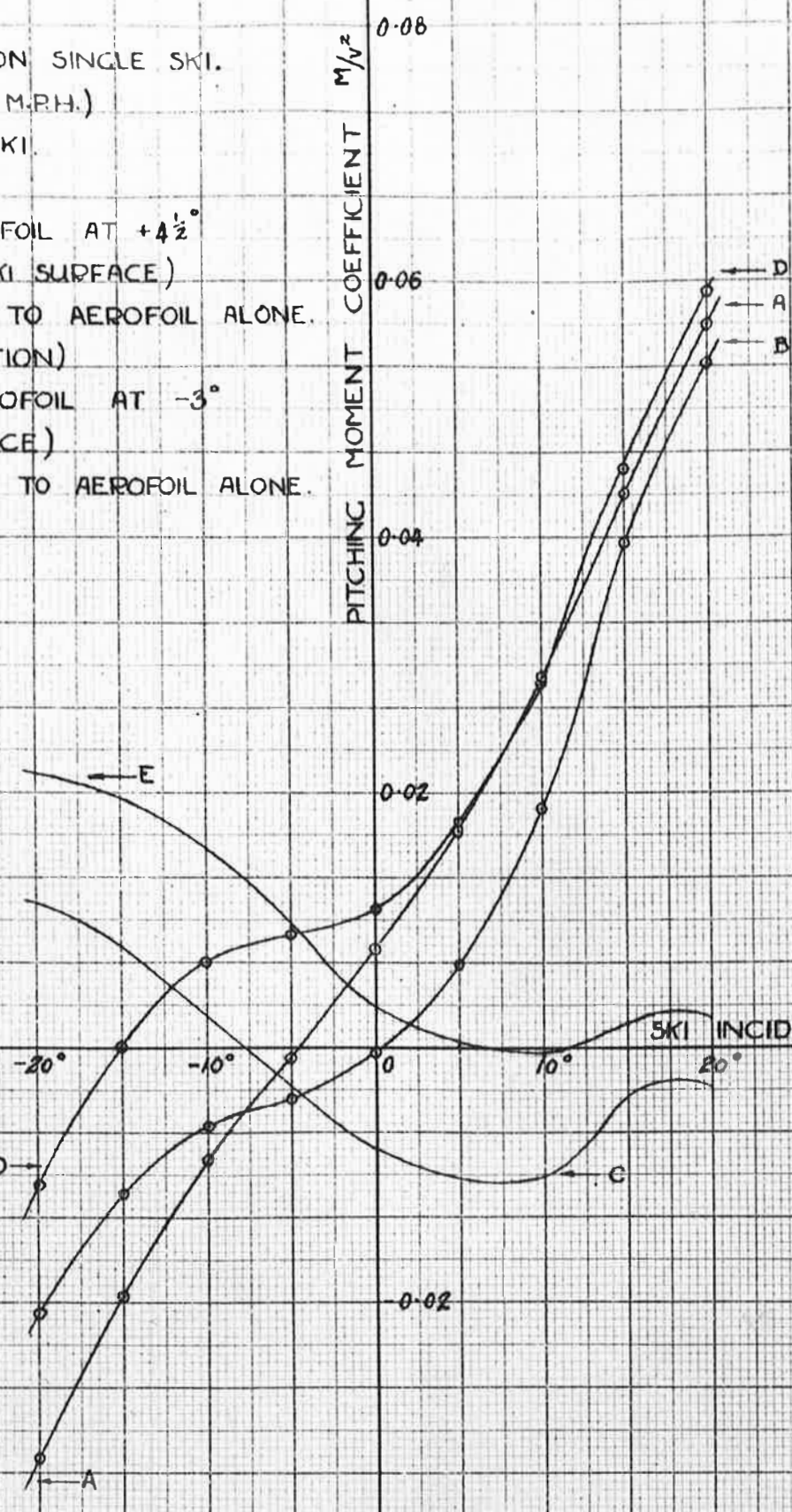
A. UNMODIFIED SKI.

B. SKI WITH AEROFOIL AT +4½°
(RELATIVE TO SKI SURFACE)

C. MOMENT DUE TO AEROFOIL ALONE.
(BY SUBTRACTION)

D. SKI WITH AEROFOIL AT -3°
(TO SKI SURFACE)

E. MOMENT DUE TO AEROFOIL ALONE.



CURVE No. 4. SIGNATURE D.J. Green. DATE 4/8/33.

NATIONAL RESEARCH LABORATORIES

R.C.A.F. SIZE "E" SKI.

PITCHING MOMENT ON SINGLE SKI.

(M IN FT. LBS. V IN M.P.H.)

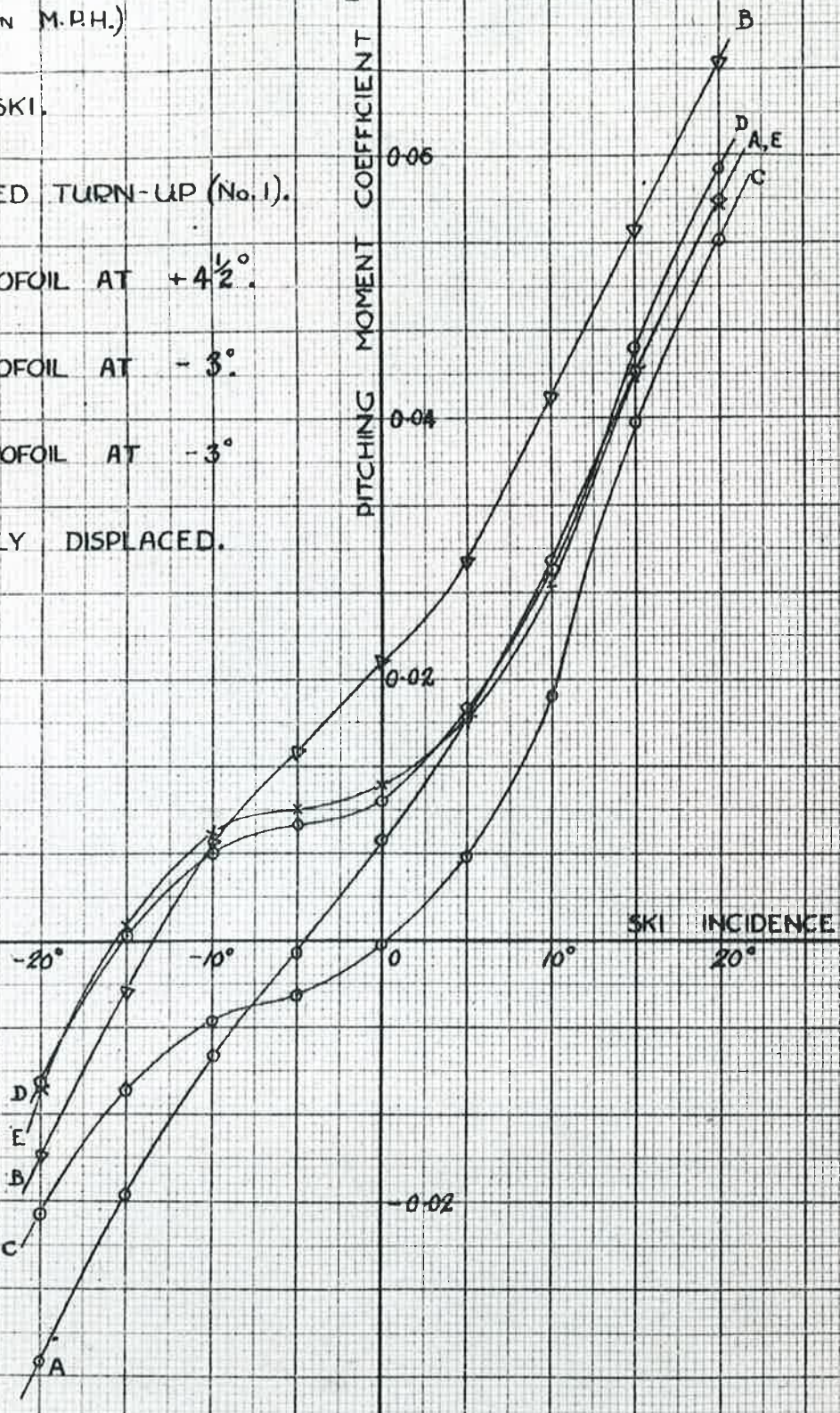
A ⊙ UNMODIFIED SKI.

B △ SKI WITH FAIRED TURN-UP (No. 1).

C ⊙ SKI WITH AEROFOIL AT $+4\frac{1}{2}°$.

D ⊙ SKI WITH AEROFOIL AT $-3°$.

E × SKI WITH AEROFOIL AT $-3°$ AND LATERALLY DISPLACED.



CURVE No. 5 SIGNATURE G.J. Green. DATE 11/8/33.

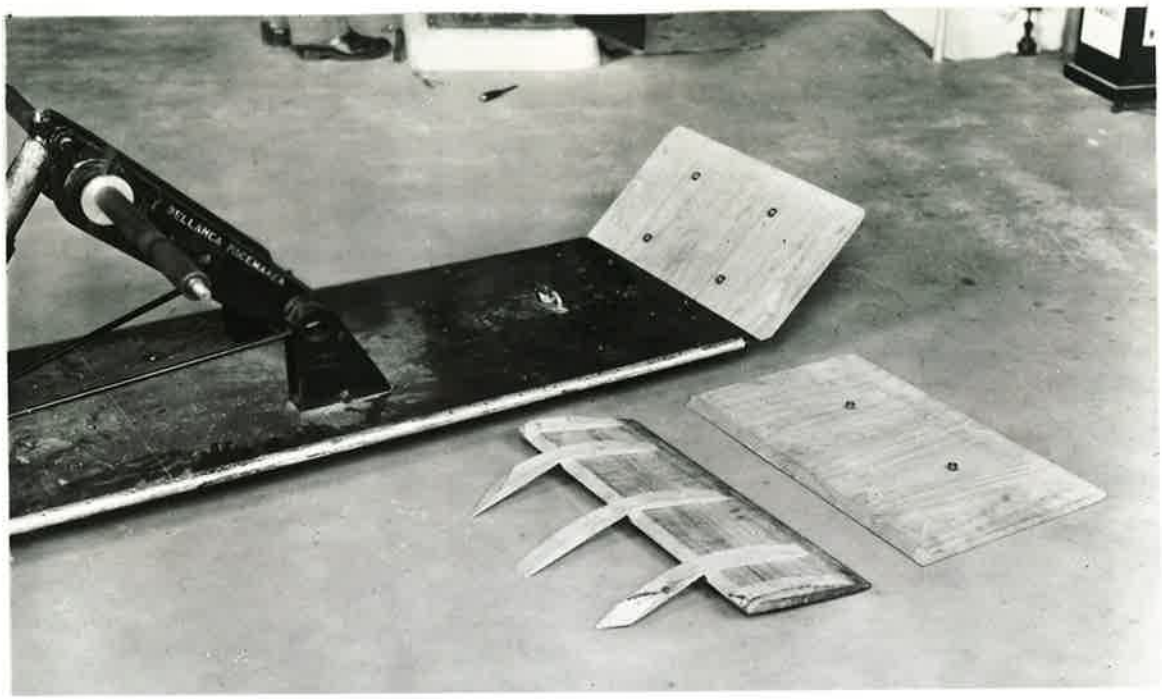


FIG. 1.

FIG. 2.

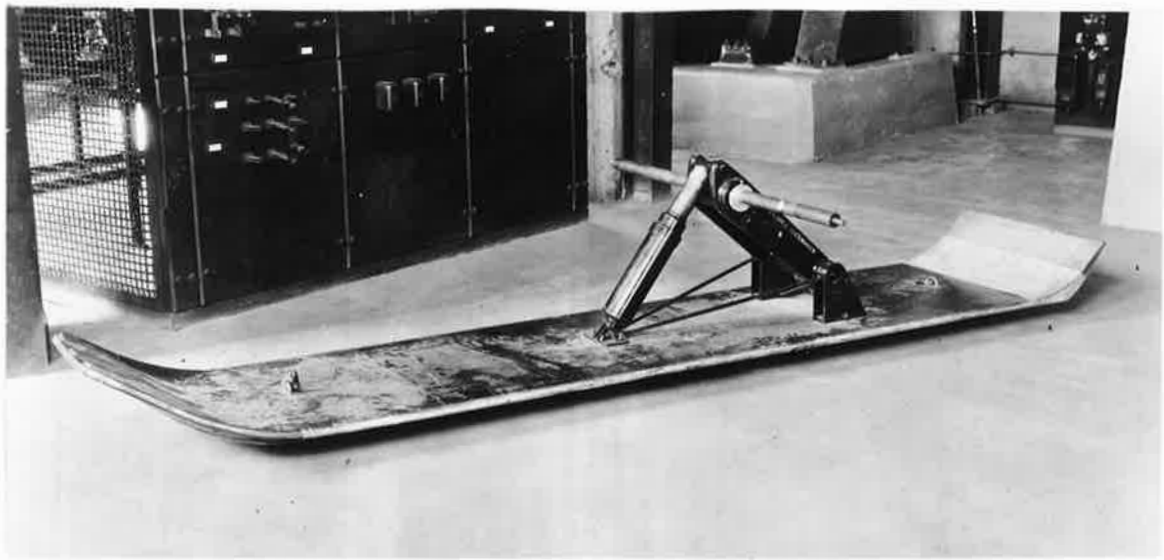


FIG. 3.

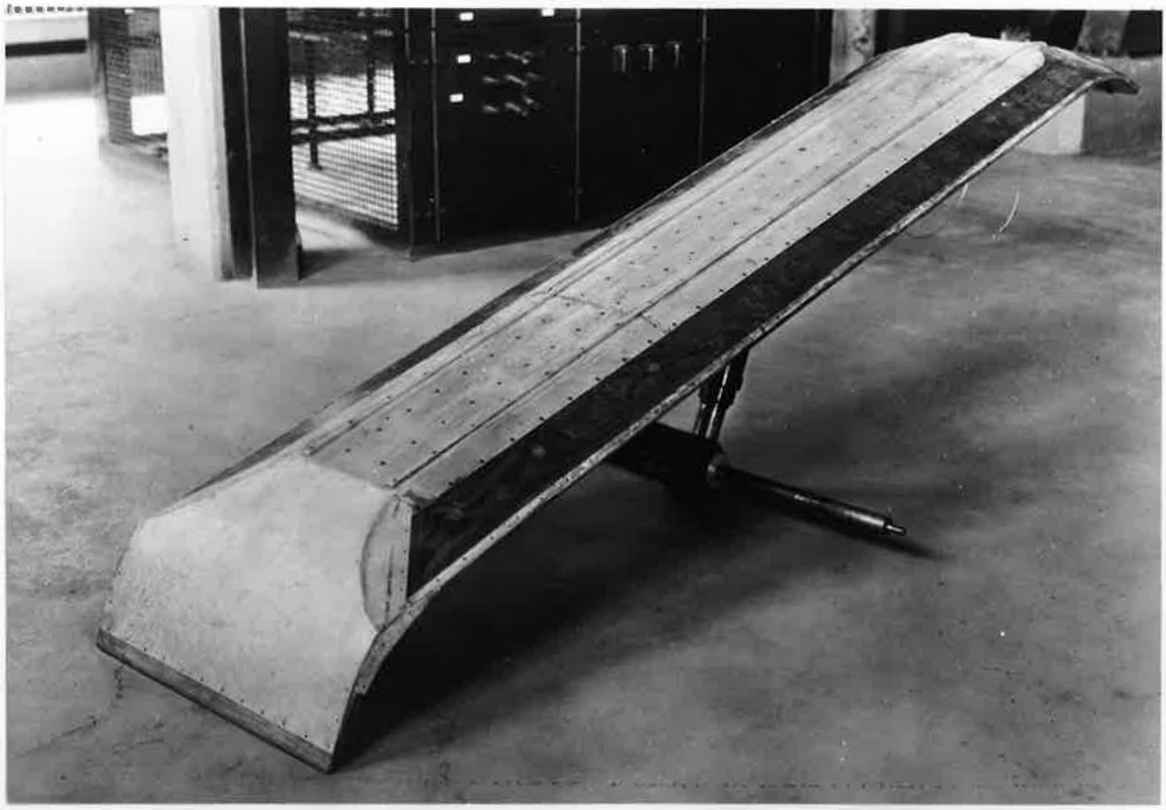
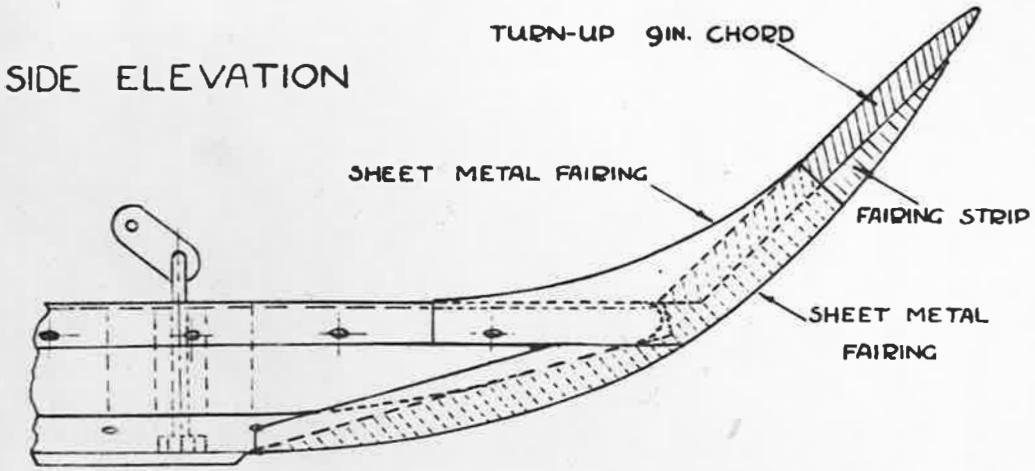
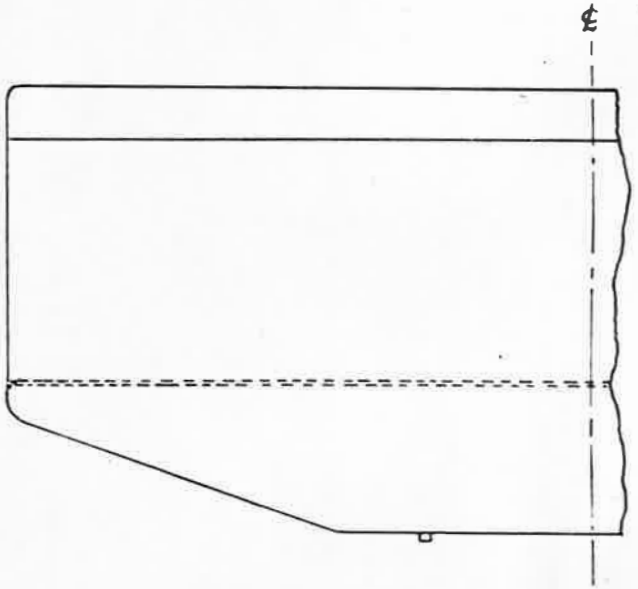


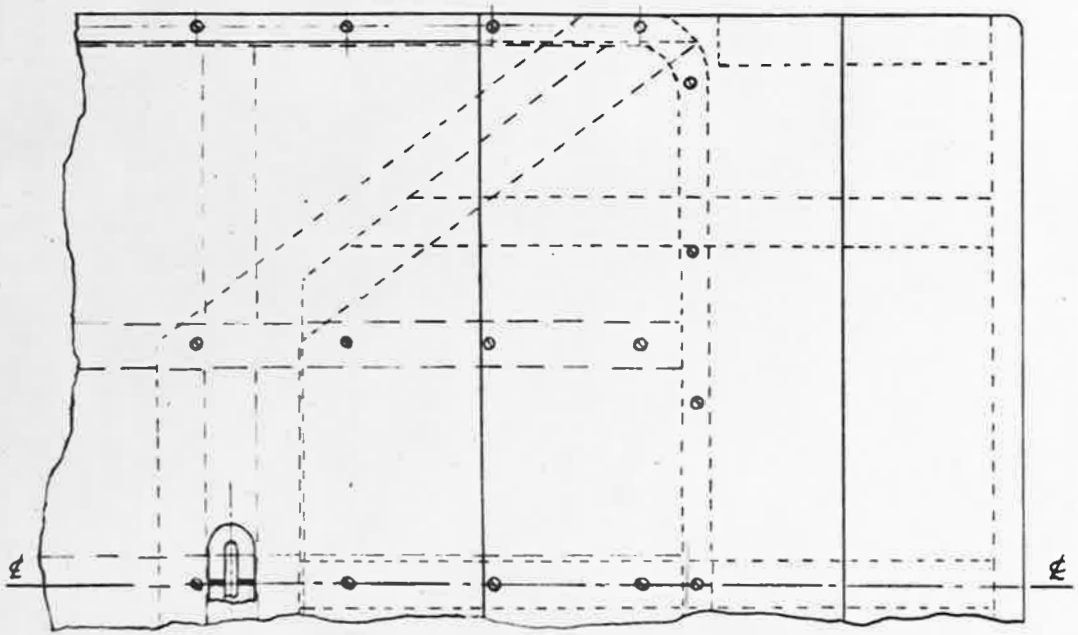
FIG. 4.

SIDE ELEVATION





END ELEVATION



PLAN

FIG. 5.

NATIONAL RESEARCH LABORATORIES

R.C.A.F. SKI SIZE "E"

REAR END WITH 9 IN.

CHORD FAIRED TURN-UP.

SCALE 1 IN = 4 IN. 14/8/33. G.J. Green.

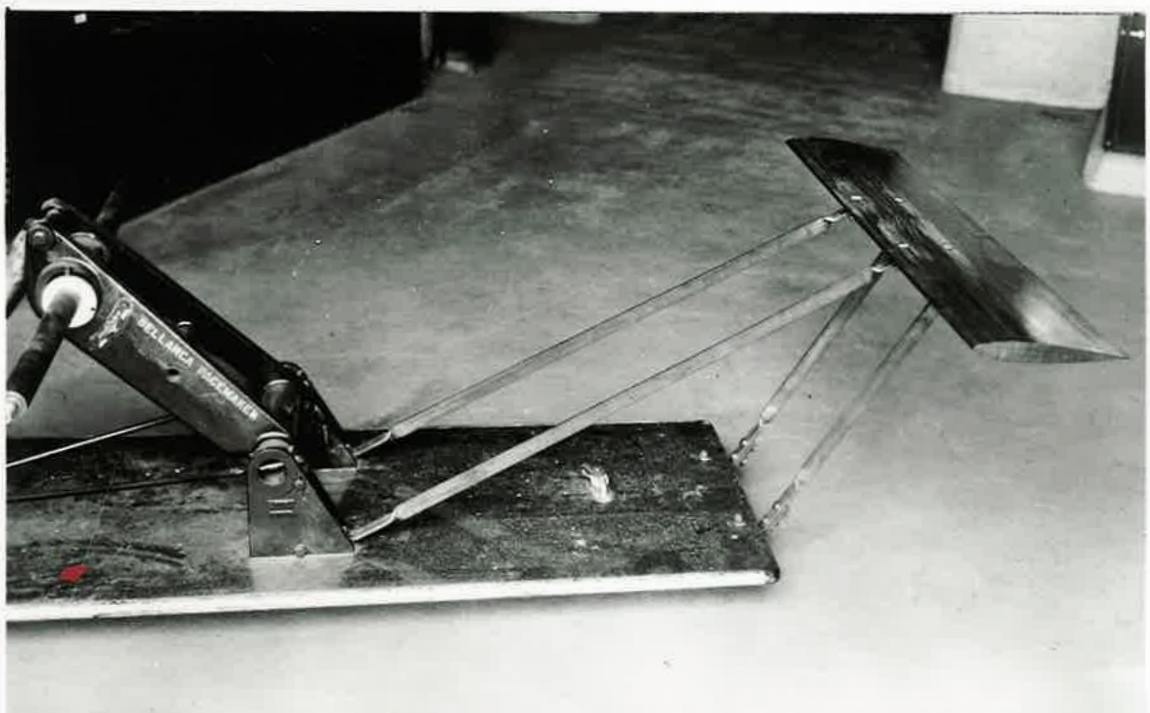


FIG. 6.